

Method for determining a position of a displaceable element as well as a wave motor

The invention relates to a method for determining a position of an element which is displaceable relative to a stator, the stator comprising at least one transducer, an electric signal being generated on the transducer, so that a wave traveling in the surface of the stator is generated.

5           The invention also relates to a wave motor comprising an element displaceable relative to a stator, the stator comprising at least a transducer by means of which a wave can be generated in the surface of the stator.

10           In a method and wave motor known from United States patent US-B2 6,331,747 waves are generated in the surface of the stator by means of transducers located on a stator. A displaceable element is displaced over the surface of the stator by means of the waves.

15           A disadvantage of the known method and wave motor is that the position of the displaceable element relative to the stator is unknown.

          Determining the position of the displaceable element relative to the stator would be possible by means of external sensors known per se, but such sensors are disadvantageous in that they take up space, are relatively expensive and form a component that has to be additionally mounted.

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          It is an object of the present invention to provide a method for determining in a simple manner the position of an element that can be displaced over a stator.

25           With the method according to the invention this object is achieved in that at least part of the wave is reflected to the transducer by the displaceable element, the position of the displaceable element relative to the stator being determined by a processor on the basis of the reflected wave.

          The wave generated in the surface of the stator by means of the transducer travels through the surface of the stator with a velocity known beforehand. The waves are

acoustic waves of which the velocity is known beforehand and depends on for example the material and the ambient conditions of the stator. As soon as the wave reaches the displaceable element, the wave is reflected completely or in part back to the transducer. By measuring the time between the generation of the wave in the transducer and the recording of the wave reflected by the displacing element by means of the transducer, for example by means of a processor, the position of the element can be determined. The time in which the emitted and reflected wave has gone to and fro through the stator to the displaceable element is multiplied by the velocity of the wave equal to twice the distance between the actuator and the displaceable element.

10 By means of the method according to the present invention it is possible also to displace the element relative to the stator by means of the waves generated by means of the transducer. So the transducer is used both for displacing the element and for determining the position of the element, while the higher harmonic wave can be used for determining the position.

15 An embodiment of the method according to the invention is characterized in that at least two transducers are provided, waves being generated by means of a first transducer for displacing the displaceable element, and waves being generated by means of a second transducer for determining the position of the displaceable element.

20 By the use of separate transducers for displacing and determining the position, each transducer can be optimized for the specific function, so that the displacement can be effected more accurately and determining the position can take place with a higher resolution.

Another embodiment of the method according to the invention is characterized in that the frequency of the waves generated by means of the first transducer is different from the frequency of the waves generated by the second transducer.

25 As a result of the different frequencies, the wave generated for determining the position can be simply distinguished from the wave for displacing the element, so that the position of the element can be determined more accurately.

The frequency of the wave for determining the position of the transducer is preferably higher than the frequency for displacing the displaceable element, because with a higher frequency the position of the element can be determined with a higher resolution.

30 Yet another embodiment of the method according to the invention is characterized in that by means of at least two transducers waves can be generated for determining the position of the displaceable element, which waves travel in the surface of the stator transversely to each other.

By means of transducers arranged in this way for determining the position of the displaceable element it is possible to determine the position of the displaceable element in various directions running transversely to each other.

A further embodiment of the method according to the invention is  
5 characterized in that the displaceable element is disposed between at least two transducers, the position being determined by means of the two transducers.

In this way the resolution with which the position is determined is higher.

The invention further has for an object to provide a wave motor by means of which the position can be simply determined of an element that can be displaced over a  
10 stator.

In the wave motor according to the invention this object is achieved in that, in operation, the position of the displaceable element relative to the stator can be determined by means of a processor from a wave reflected by the displaceable element.

By means of the processor and the transducer the position of the element  
15 relative to the stator can be determined from the time between the generation of the wave and the registration of the reflected wave as well as from the wave velocity known beforehand.

Since the stator comprises the transducer, which can also be used, as required, for generating waves for displacing the element, the wave motor is relatively compact.

Besides, such a transducer can be integrated relatively simply with the stator,  
20 so that no additional assembling activities are necessary.

A further embodiment of the wave motor according to the invention is characterized in that at least two transducers are provided, the first transducer being instrumental in generating waves for the displacement of the displaceable element, the second transducer being instrumental in generating waves for determining the position of the  
25 displaceable element.

By means of two transducers each having a function of its own it is possible to determine accurately the position of the displaceable element as well as displace the element accurately.

Yet a further embodiment of the wave motor according to the invention is  
30 characterized in that waves for determining the position of the displaceable element can be generated by means of at least two transducers, which waves, in operation, travel transversely to each other in the surface of the stator.

By means of transducers arranged in this way the position of the displaceable element in two directions running transversely to each other can be determined.

Another embodiment of the wave motor according to the invention is characterized in that the displaceable element is disposed between at least two transducers, in which the position of the displaceable element can be determined by means of the two transducers.

5 Via such an arrangement the position of the displaceable element can be determined with a higher resolution.

10 The invention will be further explained with reference to the drawings in which:

Fig. 1 shows a perspective view of a first embodiment of a wave motor according to the invention,

Fig. 2 shows a perspective view of a second embodiment of a wave motor according to the invention.

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In the Figures like component parts have like reference numerals.

20 Fig. 1 shows a wave motor 1 comprising a stator 2 extending horizontally in an X and a Y plane and a displaceable element 3 disposed on the stator 2. The surface of the stator 2 facing the element 3 is composed of a thin layer of preferably piezo-electrical material with pairs of electrodes located on both sides of the surface of the stator 2, which electrodes form the transducers 4,5 and 6,7. The transducers 4, 5, 6, 7 are for example what are called interdigital transducers (IDT). Each transducer 4, 5, 6, 7 is electrically connected to a generator (not shown).

25 An electric wave signal  $V_i = V_{0i} \sin(\omega_i t + \phi_i)$  can be produced on each transducer 4, 5, 6, 7 by means of the generators, where  $i$  is the number of the transducer. The electric wave signals generated by means of the transducers 4, 5, 6, 7 cause surface-acoustic waves to occur in the surface of the stator 2.

30 The displaceable element 3 comprises on a side facing the stator 2 spherical contact faces 8 by means of which the displaceable element 3 rests on the surface of the stator 2.

By means of the waves 11, 12 generated by means of the transducers 4, 6, the spherical contact faces 8 and, therefore, the element, are displaced.

The waves 9, 10 generated by means of the transducers 5, 7 travel through the upper surface of the stator 2 in the direction of the displaceable element 3. The moment the waves 9, 10 reach the displaceable element 3, the waves 9, 10 will be reflected completely or in part as wave 13, 14 respectively by the spherical contact faces 8 in the direction of the transducers 5, 7 respectively. The reflected wave 13, 14 is recorded as an electric wave signal by the transducers 5, 7. The transducers 5, 7 are connected to a processor (not shown) by means of which the time is recorded between the generating of the wave 9, 10 in the relevant transducer 5, 7 and the recording of the reflected wave 13, 14.

The velocity at which the waves 9, 10, 11, 12, 13, 14 travel through the piezo-electrical surface depends inter alia on the material and the ambient conditions such as temperature of the piezo-electrical material.

This wave velocity is known beforehand. Subsequently, the processor is instrumental in the computation of the position of the displaceable element 3 from the time and velocity.

Since the position of the element is simultaneously determined by means of the waves generated by both transducer 5 and transducer 7, determining the position can be effected with a relatively high resolution.

Based on the position of the displaceable element 3 on the stator 2 the electric signal to the transducers 4, 6 can be driven such that the displaceable element 3 is moved to a desired position.

The waves 9, 10 generated by means of the transducers 5, 7 preferably have a different higher frequency  $f$  than the waves 11, 12 generated by means of the transducers 4, 6. The higher the frequency  $f$  the smaller the wavelength  $\lambda$ . Since the transducers 5, 7 generate waves with a relatively high frequency  $f$ , the wavelength  $\lambda$  of the waves 9, 10 is relatively short, so that the dimension of the transducers 5, 7 can be relatively small and require little surface area on the stator. In addition, interference between the waves 9, 10, 13, 14 on the one hand and the waves 11, 12 on the other, with relatively large frequency differences between the waves 9, 10, 13, 14 of the transducers 5, 7 and the waves 11, 12 of the transducers 4, 6, will substantially not disturb the displacement and measurement. A high wave frequency of the waves 9, 10, 13, 14 is furthermore advantageous in that the displacements of the displaceable element 3 is recorded with a high resolution.

Fig. 2 shows a second embodiment of the wave motor 21 according to the invention which, besides two pairs of transducers 4, 5; 6, 7, comprises four further transducer pairs 22, 23; 24, 25; 26, 27; 28, 29 which are accommodated on a stator 30. The pairs 22, 23

and 24, 25 are positioned opposite to each other in the Y direction. The pairs 26, 27 and 28, 29 are also positioned opposite to each other in the Y direction. The pairs 22, 23 and 26, 27 and 24, 25 and 28, 29 respectively are positioned side by side in X-direction. A displaceable element 31 is disposed on the stator 30 between the transducers. The stator 30 with the transducers 4-7, 22-29 disposed thereon form a displacement system for the displaceable element 31 disposed thereon, which rests with spherical contact faces 32 on the surface of the stator 30. The element 31 is displaceable over the stator surface 30 in both X and Y direction between the transducers 4-7, 22-29.

The transducers are connected to generators for generating electric wave signals on the transducers 4, 5, 6, 7, 22, 23, 24, 25, 26, 27, 28, 29.

The element 31 can be displaced by the waves 11, 12 in and contrary to the direction indicated by the arrow X by the driving of the transducers 4, 6 whereas, as a result of the driving of the transducers 22, 24, 26, 28 the element 31 can be displaced in and contrary to the direction indicated by the arrow Y by means of the waves 35, 36, 37, 38. In addition, it is possible to rotate the element 31 in and contrary to the direction indicated by the arrow  $R_z$  by simultaneously driving the transducers 22, 28 and 24, 26 respectively.

In similar fashion to the one described with reference to Fig. 1, the position of the element 31 on the surface of the stator 30 can be determined by the transducers 5, 7, 23, 25, 27, and 29.

The position of the element in X-direction is then determined by means of the transducers 5, 7 and the position of the element in Y-direction and in  $R_z$  direction is determined by means of the transducers 23, 25, 27, 29.

It is alternatively possible to make the entire stator of piezo-electrical material.

It is also possible to both displace the element 3 and determine the position of the element by means of a single transducer. The waves by means of which the element is displaced will be reflected completely or partly by the element.

It is also possible to utilize only a single or a single pair of transducers both for displacing and for determining the position of the element.

It is also possible to utilize other displacing systems for displacing the element.

In order to obtain a proper measurement it is possible to effect measurements at the stator prior to the displacement and the measurement of the displacement of the element, while waves are generated in the stator with the element not yet being provided on the stator. This provides a proper reference.

In order to increase the accuracy of the measurements it is possible to measure the temperature of the stator since the wave velocity also depends on temperature. It is also possible to determine the wave velocity and thus the temperature of the stator from the measured distance when the object has a known position relative to the actuator.

5                   It is also possible to apply what are called comb transducers or wedge transducers.

It is alternatively possible to utilize different shapes in lieu of spherical contact faces 8.